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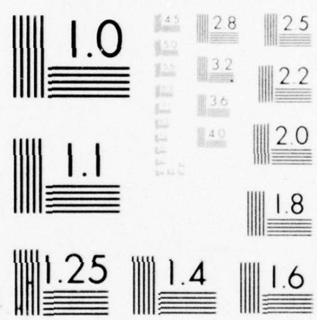

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ON THE MOON ILLUSION*

M. C. Corum

The Rand Corporation

June 1976

*This paper is a variation of the author's thesis, written in partial fulfillment of the requirements for the M.A. degree at California State University, Los Angeles, March 1973. I am very grateful to the following former and current Rand staff members for their advice and technical support: Palmer Van Dyke who photographed the slides used in Experiment Two; Richard Murrow who provided the stereo camera and much advice on stereo equipment; Hugh Moshin who provided me with the use of an eye chart for Experiment Two; Gerhard Schilling, Harold Petersen and George Dietrich who also provided valuable technical advice. I also wish to thank the many Rand employees who served as subjects and Mr. Stanley Terebinski of the Santa Monica College Psychology Department for providing me with subjects from his classes.

ABSTRACT

Current hypotheses attempting to explain the moon illusion are reviewed. Two experiments were conducted which tested the contextual-effects hypothesis and a variation of the size-distance invariance hypothesis. The first experiment involved scenes in two dimensional space. No illusion was obtained. The second experiment utilized scenes presented on slides, both regular and stereo. A modest illusion was obtained with stereo slides that depicted great distance and offered few contextual cues thus producing a visual scene of ambiguous depth. Neither the contextual-effects hypothesis or the size-distance invariance hypothesis thoroughly explained this result. Another hypothesis was presented, which might handle many inconsistencies that have cropped up not only in past experiments but in the second experiment here. This hypothesis has to do with the possible anisotropy of visual space and how it could be handled using Luneberg's mathematical theory of binocular vision.

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INTRODUCTION

People have been puzzled for centuries over the fact that the moon appears larger on the horizon than when it is in the zenith of the sky. That the moon seems larger on the horizon is indeed an illusion, for it measures the same size as when it is in the zenith. Moreover, the illusion can be diminished by looking at the large horizon moon through a circle made by one's finger and thumb.

Many explanations of this phenomenon have been offered. Berkeley (see Helmholtz, 1925) postulated that the hazy appearance of the moon near the horizon and its low luminosity were responsible. Others have suggested that refraction of the rays of light by vapor in the atmosphere created the illusion. Generally speaking, however, the hypotheses that have been proposed to explain the moon illusion fall into two major classes: (1) the size-distance invariance hypothesis, and (2) the angle-of-regard hypothesis. A third hypothesis which has not received such widespread discussion concerns contextual effects. In addition, it has been suggested that Luneberg's analysis of perceptual space in terms of alleged non-Euclidean properties may have some bearing on understanding the illusion. I shall first describe each of these classes of hypotheses in some detail and then describe some experiments that I designed to explore some aspects of the hypotheses.

SIZE-DISTANCE INVARIANCE HYPOTHESIS

Ptolemy of Alexandria (A.D. 150) is credited with the first recorded explanation of the moon illusion. He argued (see Helmholtz, 1925, or Boring, 1943) that a filled space looks longer than an empty space. In other words, the distance to the horizon seems greater than the distance to the vault of the heavens because it is filled with objects. Many writers have found it convenient to put Ptolemy's explanation in the context of describing the sky as an observer would perceive it--an ellipsoid where the zenith of the sky is like a flattened dome. The horizon thus is perceived to be farther away than the vault of the sky. With this in mind, we note that when two objects of equal

size are seen in the sky the one at a greater apparent distance appears larger. Assuming that the moon is physically the same size when it is in either the zenith or on the horizon (a safe assumption in this case) then it must appear larger on the horizon. Formulated in more modern terms, this result is a consequence of the well known phenomenon of size-distance invariance (or perceptual constancy): given two retinal images of equal size, the image associated with cues indicating greater distance appears larger.

The relevance of the size-distance invariance hypothesis to the moon illusion can be seen in Emmert's Law, a variation of the hypothesis, which states that the apparent size of an afterimage is "directly proportional to its apparent distance from the observer" (Boring, 1942:299). In other words, the perceived size of an afterimage, as seen against surfaces at different distances, is a direct function of the distance of the surface frcm the observer and not of the size of the original object from which the afterimage was obtained. King and Gruber (1962) for example, had subjects project afterimages of two-inch squares into a daylight sky from a rooftop. The "surfaces" of the sky used were near the horizon, 45° elevation, and 90° elevation. The mean size-ratio for the horizon/90° comparison was 1.625. For the horizon/45° comparison, the mean size-ratio was 1.5. They conclude that "the perceived size of the afterimage varies in a manner predictable from Emmert's Law and the reported appearance of the sky as a flattened dome" (King and Gruber, 1962:1126).

During the past ten or fifteen years, however, there has been increasing dissatisfaction with the use of this hypothesis in explaining perceptual phenomena in general. Epstein, Park, and Casey (1961), in their review of the status of the size-distance hypothesis, concluded that there is confusion in terms of defining distance experimentally. There is apparently no linear relationship between apparent and physical distance, and no way of comparing experiments that use one kind of distance judgement to the exclusion of the other. There are also methodological problems in obtaining size-distance judgements, as well as much inter-subject variability. However, Rock and Kaufman (1962:1028) make the point that

> to support the invariance hypothesis one need only to show that specifiable changes in registered* distance (as indicated by convergence, accommodation, and so on) yield predictable changes in phenomenal size; not that changes in phenomenal or judged distance yield predictable changes in phenomenal size.

ANGLE-OF-REGARD HYPOTHESIS

Some years ago, Boring (1943) contributed to the issue by asserting that, contrary to Ptolemy's observations, most observers perceive the zenith moon as more *distant* than the horizon moon. Thus, according to the principal of size constancy, the zenith moon should appear *larger* than the horizon moon, a conclusion contrary to common observation. Therefore, Boring concludes, "in the case of the moon it is not perceived distance that determines size. On the contrary, the perceived size would seem to determine the perceived distance." (Boring, 1943: 56).

Further, Boring cites Shur's work in 1925, in which artificial moons were projected indoors on walls and ceiling. When the moons were thirty-three meters away from a subject, an illusion (with a ratio of 1/2) was obtained, and Boring noted that when a moon is thirty-three meters above the floor cues to perception of that distance are not fully adequate to judge the distance as when they are along the ground. He thus concluded that "the illusion is really the smallness of the moon in elevation when seen through empty space, not its bigness on the horizon." (*Ibid.)*

As an alternative explanation of the moon illusion, Boring proposed, on the basis of his and his colleagues' experiments, that the apparent change in size of the moon is associated with the elevation of the observer's eyes.

Holway and Boring (1940a) had subjects view both the horizon and zenith moons from the top of a building and make matching judgements from a variable disk of light a few meters away and to the side. They had subjects view the horizon moon while lying supine and with head tilted backward, duplicating as nearly as possible the normal position

*Size of retinal image.

of the eyes in viewing the zenith moon. The ratio of matching the horizon moon to the zenith moon when viewed normally was 1.67 and the ratio of matching the zenith moon to the horizon moon from a supine position was 1.47, thus reversing the normal illusion. In a second experiment (1940b), the same authors used mirrors so that the moon could be viewed by the subjects a bit more comfortably anywhere in the sky. Using themselves as subjects, they obtained an illusion with a ratio of 2.0 with the eyes raised, and no illusion at all when the head was raised.

The angle-of-regard theory has come under much fire, most recently from Kaufman and Rock (1962). Like most researchers trying to duplicate Holway and Boring's experiments, these investigators were unable to obtain an illusion effect. They note that in real life (outside the experimental laboratory), the illusion persists no matter how we tilt our head and eyes.

Kaufman and Rock criticize Holway and Boring's work first for methodological reasons: not only did they serve as their own subjects, but their other subjects were very familiar with the experimental hypothesis. In addition, Holway and Boring's comparison disk was in near linear distance, where convergence and accommodation cues could aid subjects in making size judgements--cues which are not present when the actual illusion is experienced.

They also criticized Holway and Boring on a theoretical point, which was Holway and Boring's basis for rejecting the size-distance hypothesis. Kaufman and Rock argue that an observer, when asked whether the horizon moon or the zenith moon is closer, compares two different sized moons, and--unaware that the distance cue has already determined the size for him--is using the size of the moons to make a judgement. To prove this point, they conducted two experiments. In the first, they had subjects judge the distance of a large disk and a small disk; the small disk was unanimously declared to be farther away. In the second experiment, they had subjects make judgements as to whether a point on the horizon of an ellipsoidal sky was farther or nearer than a point in the zenith of the sky. Nine of their ten subjects reported that the horizon point was farther. They conclude, then, that the

problem of the horizon moon appearing closer when it is perceived on a more distant horizon is one of perceptual judgement after the fact, rather than a perceptual reaction.

CONTEXTUAL EFFECTS

A third hypothesis regarding the moon illusion has also received some attention from Rock and Kaufman (1962). It suggests that objects on the terrain, such as buildings, signs, roads, etc., serve as a two-dimensional context that increases the size of the moon as it is seen adjacent to terrain objects.

Kaufman and Rock did not obtain an illusion effect when subjects observed disks of light projected horizontally and on the zenith dome in a totally darkened planetarium, and their conclusion was that terrain cues were indeed necessary. They then tried to obtain an illusion using slides of terrain indoors. "On the whole, only a negligible illusion was obtained when a disk seen above the terrain on the screen was compared with a disk seen within a homogeneous surround" (Rock and Kaufman, 1962:1028). They then drew a control slide in which the essential structural details of a terrain were present but that lacked all cues of depth, and no illusion effect was obtained at all. They go on to add that if terrain cues are an important factor in creating the illusion, it is because they provide contextual effects which in turn act as depth cues.

There has been successful experimental work in which an illusion was produced indoors. Shur's work was previously discussed, and Leibowitz and Hartman (1959) obtained significant results when subjects in a darkened theater made size comparisons of disks seen overhead with disks seen straight ahead. However, these experiments cannot be said to actually test the contextual effects hypothesis. They do indicate, however, that the illusion can be duplicated in the laboratory--something that Kaufman and Rock concluded could not be done, based on their results discussed in the previous paragraph.

KAUFMAN AND ROCK'S WORK

By far the most extensive work on the moon illusion has been done by Kaufman and Rock (1962a), and Rock and Kaufman (1962). (See also Kaufman and Rock, 1962b, a condensation of the two articles above.) In addition to providing a comprehensive review of the literature to date, they tested each of the hypotheses discussed above and introduced as experimental variables other effects which have been mentioned as possibly affecting the illusion; color and brightness of the horizon moon and the effects of clouds (none of which were found to be related to the illusion). All experiments were done with the same kind of equipment and in similar environs.

As can be concluded from the above discussion, Kaufman and Rock reject the angle-of-regard hypothesis. They also reject the contextual effects hypothesis, noting (1) that terrain normally does not surround the the moon, (2) that their experiments indoors yielded only a negligible illusion effect, and (3) that an illusion can be observed with almost no "terrain," i.e., with only an ocean providing the horizon. This suggests, as Kaufman and Rock do, that more than one parameter may be at work in creating the illusion.

Kaufman and Rock concluded by embracing a modified version of the size-distance invariance hypothesis, in which contextual effects act as depth cues that provide the crucial stimulus correlates of distance in a perceived scene. They arrived at this conclusion after conducting the following experiment. Using two devices which permitted them to view standard and comparison disks of light or artificial moons on the sky, subjects viewed a horizon whose apparent distance from the viewing point on top of a building was approximately two miles. The average illusion ratio obtained on a clear day was 1.4; with broken clouds, 1.54; and on an overcast day, 1.58. When subjects made observations with apparent distance approximately 2000 feet, the comparable ratios were 1.28, 1.35, and 1.45.

Kaufman and Rock feel that configurational properties, or relationships within the stimulus pattern such as perspective and interposition, are the crucial stimulus correlates that provide the observer with the necessary information about distance. They did not go on to investigate what these specific configurational properties might be in a given scene,

but suggested that such experiments would lead to a better understanding of the stimulus correlates that create the moon illusion (Rock and Kaufman, 1962:1028).

LUNEBERG'S THEORY OF BINOCULAR VISION

As a final consideration, Luneberg (1947) has postulated a theory of binocular vision in which he attempts to establish mathematically the relationship between physical space and visual space. Additional experimental work based on Luneberg's theory was carried out by Blank (1953), who formalized and somewhat modified Luneberg's mathematical analysis. Briefly, Luneberg's mathematical theory of visual space is based on the following assumptions. Visual space, in contrast to physical space, is non-Euclidean in character.* Relying on Blumenfeld's (Boring, 1942) experiments with visual alleys, Luneberg concluded that this non-Euclidean visual space is in fact a homogeneous Riemannian space of negative curvature; that is, a hyperbolic space.

Intriguing and suggestive as Luneberg's theory is, however, it is not clear how it might be directly applied to the problem of the moon illusion. On the other hand, it raises the possibility of considering the illusion in a novel theoretical context; that is, in terms of the special properties of visual as contrasted with physical space. It should be pointed out that Luneberg's theory has so far been investigated experimentally in the horizontal (two-dimensional) plane only, although Blank (1953) has extended the theory mathematically to the case of three-dimensional space (that is, to an infinite family of planes elevated above the horizontal plane). What has been taken for granted, however, both by Luneberg and by Blank, is the isotropic character of visual space, and it is here that the theory becomes especially suggestive. For if visual space were in fact anisotropic (that is, did not have the same metric properties in all directions) such a result would provide the basis for an alternative approach to the moon illusion problem.

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*It should be noted that this distinction is based upon the presumed Newtonian properties of *local* physical space. According to general relativity theory, physical space is in fact non-Euclidean, but on a much larger scale than we are considering here.

Rock and Kaufman reject the suggestion that visual space is anisotropic on the grounds that (1) the necessity of such an explanation has not been established and (2) the absence of significant effects in their own dark-room experiments "argues against any inherent anisotropy of three-dimensional space" (1962: 1050). In reply to Kaufman and Rock, however, one could note that it is at least clear that were the anisotropic character of visual space to be established experimentally, it would hold the promise of considerably simplifying present theorizing about the moon illusion, which has become increasingly complex as the accumulation of further (and often conflicting) evidence has led to a multiplication of rather ill-defined experimental parameters.

In this regard, certain experimental data discussed by Tschermak-Seysenegg (1952) raises anew the issue of the intrinsic directional properties of visual space. Although Tschermak-Seysenegg gives no specifics regarding experimental conditions, he makes the following statement:

> The surface of the earth appears subjectively saucer-shaped. The sky appears like a depressed vault. Its curvature varies according to cloudiness and illumination--strongly curved at night, less curved on a cloudless day, flat when covered with gray clouds. In case of an unrestricted view, the sky seems to reach the mid-point of the arc between horizon and zenith at an angle of elevation of $21.47 \pm .08°$, $29.95°$ on a moonless night, $26.55°$ in moonlight, $24.69°$ with a restricted view, $20.55°$ for a sky wholly covered (*Ibid.*: 215).

He then states that use of a mathematical formulation brings one to the conclusion that "equal objective visual angles or arcs of the sky are overestimated at low elevations and underestimated at high elevations (from about 35° on). Consequently, an airplane, for instance, seems considerably higher and closer when near the horizon" (*Ibid.*). He concludes, however, that there is no adequate explanation for this phenomenon.

Although the present experiments were not designed to explore the hypothesis of anisotropy of visual space, it appears to provide an interesting theoretical context for discussing experimental results. I will return to this issue in the general discussion following the description of my experimental procedures and results.

THE PROBLEM

I am not interested in furthering the controversy over the angle-of-regard theory. I feel that Kaufman and Rock indicated adequately enough its inadequacies in explaining the moon illusion. Instead, I wish to explore further what Kaufman and Rock call the configurational properties of the stimulus pattern in a scene, which they feel are responsible for the moon illusion. Configurational properties in a scene can be defined to mean relationships of objects due to interposition, distance from each other and viewer, perspective, etc.

In addition, I am not convinced that Kaufman and Rock have rejected the contextual effects hypothesis for the right reasons. If other experimenters have been successful in conducting dark-room experiments perhaps Kaufman and Rock erroneously rejected this hypothesis because of methodological problems. Also, Kaufman and Rock seem to be using the terms "contextual effect" and "configurational property" synonymously. Thus, if they are right in their conclusion, the use of contextual effects in two-dimensional scenes will not produce an illusion effect. But the addition of the third dimension would verify their findings.

There are at least two ways in which the configurational properties of a scene can be explored experimentally. In one, a scene beginning with blank two-dimensional space may be built up to a scene with filled three-dimensional space. A subject's judgements about the size of the "moon" appearing in various scenes could indicate at what point configurational effects begin to influence the illusion. A second method of exploring this problem involves using many scenes, each with different configurational properties. Ideally, certain scenes would result in an illusion effect and others would not. Experiment 1 utilizes the first method and Experiment 2 utilizes the second.

Experiment 1 is divided into two parts. In Part 1, flat vertical scenes are presented to a subject, with different aspects of the scene added or taken away in successive trials. Part 2 involves adding objects to the viewing space between the subject and the same scenes used in Part 1. Two different space configurations are utilized: the scenes are viewed either at the end of an "alley" (to be defined) or through

a maze of randomly placed objects. For each scene presented in both Parts 1 and 2, subjects will be asked to look at a circle either on the horizon of the scene or in the zenith, and after it is removed, to pick the same size circle from a large sample of different-sized circles. According to the results of Kaufman and Rock, a moon illusion should not occur in Part 1 where only context effects are used. However, with the added cues of depth in Part 2, an illusion effect should be obtained, if it is indeed depth that is necessary to create the illusion.

Experience 2 involves the use of stereoscopically presented slides. Stereo slides (slides of scenes photographed using a stereo camera) are presented to subjects with stereo equipment; the subjects are asked, after viewing a circle of light projected on the empty screen, to pick the same size circle from a series of circles of light projected onto the stereo scene. In addition, slides of the same or similar scenes photographed with a nonstereo camera are shown to a different group of subjects using the same procedure. Again, according to the results of Kaufman and Rock, a moon illusion should be obtained using the stereo slides where the added dimension of depth is present, and an illusion should not be obtained with the normal two-dimensional slides. In addition, it is conjectured that the illusion will vary with the different configurational properties of the various scenes in the stereo experiment.

EXPERIMENT ONE

The purpose of Experiment 1 was to determine whether a moon illusion could be obtained using scenery with a complete absence of or minimal presence of three-dimensional space. There are two parts to the experiment. In the first, only sizes and shapes of objects are available to give any kind of distance cues. In the second, objects are placed between the subject and the scene to suggest three-dimensional space.

METHOD

Equipment. Subjects viewed scenes which were placed on a large cork-covered wall overlaid with medium blue felt. Pale green curtains were drawn to restrict the viewing area to 53 inches in width and 84 inches in height. A large table 5 feet by 6 feet, and 40 inches high, stood between the subject and the wall and it was covered with green felt. The distance from the subject to the wall was 8 feet. In Part 1, the subject sat in a chair 31 inches high and in Part 2 sat in a chair 18-1/2 inches high.

Test Materials. Scenes were placed on the blue felt background using plain felt and felt-backed pictures, depicting the following subjects:

Scenes:

1. "Plain blue sky";
2. "Blue sky and green grass or dark blue ocean";
3. A cluster of "city buildings" made out of felt;
4. Two clusters of "city buildings" made from both felt and pictures, with "roads" made out of felt in front of the clusters;
5. "Sea scape with large lighthouse near cliff" made out of felt;
6. "Sea scape with small lighthouse near cliff" made from felt and pictures.

All scenes were centered in the middle of the viewing area directly in front of the subject.

Standard and Stimulus Circles: To represent the "moon" circles of sizes varying in 1/8 inch increments from 1 inch to 2-3/4 inches in diameter were made from gold-colored felt. Three duplicates of each size were placed in random order on a board to the side of the viewing area for the subject to choose from when asked to choose a circle that matched the standard. This board was covered by a curtain at all times and uncovered only when the subject was asked to choose the circle. The standard circles used by the experimenter were duplicates of the stimulus circles picked by the subjects.

Table Top Objects: In part 2, three sets of objects were displayed on the table when the scenes were presented a second time. The first set of objects were ten small artificial "pine trees" 5-1/2 inches tall which the experimenter placed on the table in front of the subject five along each side of an "alley" that the subject made with strings attached to the far side of the table in front of him. The alley thus made was not actually parallel, since the subject moved the strings while his eyes were level with the top of the table. His instructions were to place the strings so that they looked parallel to him (equally far apart the whole distance of the table). Thus the end of the alley closest to the subject was about half the width of the alley at the other end of the table. The width of the alley at the far end was set at a standard 20 inches for every subject. After the trees were placed the strings were removed. All scenes were centered in the "alley" as the subject looked down it.

The second set of objects were 12 plastic rounded cubes of various colors spread randomly along the table directly in front of the subject. Their sizes ranged in approximate 1/8 inch increments, from 1-1/8 inches wide and 3/4 inches tall to 2-3/4 inches wide and 2-1/4 inches tall.

The third set of objects were two of the above cubes, the largest placed directly in front of the subject and a smaller one placed at the far end of the table.

All scenes in Part 2 were viewed by the subject while seated in the shorter chair so that his eyes were level with the top of the table.

<u>Subjects</u>. The eight subjects were all employees of The Rand Corporation. Six subjects were men and four of the eight were professional staff members. The other four were administrative staff members.

<u>Procedure</u>. At the beginning of the experiment the subject was seated in the higher chair facing the board where the scenes would be presented. The instructions were then presented:

> I'm going to exhibit several different scenes on the board. In the first part of the experiment you will view them by themselves sitting in the high chair. In the second part you will sit in a lower chair and view them in relation to objects on the table. I will place a yellow circle on the top of the board or at eye level, and you may look at it for five seconds. After I remove the circle your job is to choose the same size circle from this board. (Pull curtain back.) You may use the letters along the top and numbers along the side to help you identify the circle you choose. Then I will place the circle you have chosen in the opposite spot on the board. If I placed the standard circle on the horizon I will put the circle you choose on the top of the board. You may choose a second or third circle if your earlier choice was unsatisfactory. But I cannot show the standard circle again. Any questions? You may take a break during scene changes if you like.

Part 1, scenes 1 through 6 were then presented. Scenes 3, 4, 5 and 6 were presented in randomized order for each subject. A standard circle was shown to the subject at either eye level or high above the scene at the top of the wall. After the circle was removed from the subject's sight he was then allowed to choose another circle which he perceived to be the same size. There were six trials for each scene and the standard circle for any given scene was placed in the same location for all six trials. The standard circle was alternately presented at the horizon or at the zenith on each succeeding scene.

In Part 1, scene 1 was repeated after all scenes had been completed as a control measure. Part 2 was then begun after a short break. The cubes and trees were randomly presented with each of the scenes.

All subjects had an equal number of trials (78). The total time of the experiment for each subject was two hours. No subject expressed fatigue or complained about the difficulty of the task. At the end of

experiment the subject was asked if he formed any strategy for picking the right size circle to match the stimulus. He was also asked whether, at any time, the experimental circle seemed larger or smaller than the standard, independently of his decision-making about his choices.

RESULTS

Analyses of variances were performed to identify differences existing between judgements in Part 1 and Part 2. A ratio score was calculated for each trial in each scene by obtaining the ratio of the experimental circle to the standard circle in the following manner. If a subject did experience an illusion effect he would have to choose a circle smaller than the standard when the standard was in the zenith, and a circle larger than the standard when the standard was on the horizon. Thus, ratios were calculated as $\frac{\text{standard}}{\text{exp. circle}}$ when the standard circle was in the zenith and as $\frac{\text{exp. circle}}{\text{standard}}$ when the standard circle was on the horizon. This resulted in a ratio score greater than one when the illusion was being perceived. One analysis was performed using the ratio scores based on subjects' corrected matches. A second analysis used ratio scores representing subjects' first choices.

	F for First Match	F for Corrected Matches	Degrees of Freedom
Tasks	0	0	$\frac{1}{7}$
Subjects	6.67^{**}	7.57^{**}	$\frac{7}{560}$
Interaction	-2.34	.57	$\frac{7}{560}$

$^{**}p<.01$

A Newman-Keuls analysis of the corrected match ratio scores revealed that the high F score indicating differences between subjects on both first and corrected matches, could be attributed to two subjects' ratio scores differing from the others'--they were a bit lower. This suggests that there were individual differences among subjects in their responses which were not affected by the experimental variables.

Subjects' verbal reports at the conclusion of the experiment indicated that most had formed some sort of strategy. The strategies varied but a couple of subjects tried to judge the size of the diameter of the

standard circle either by comparing it to the rest of the scenery or by relying on memory: "It looks like one inch." Others used a classification system. Seven of the eight subjects reported that the horizon circle looked larger than the standard circle when it was the circle picked by them, and most of these seven also said that the zenith circle looked smaller than the standard circle when it was placed in the scene. All said they learned to compensate for this and/or ignore it. Some subjects also agreed that the table top objects make the task in Part 2 more difficult.

DISCUSSION

In general, the results indicate that the null hypothesis was proven: i.e., that a moon illusion cannot be obtained using scenery with a complete or near-complete lack of real distance. Since subjects reported a small illusion effect it might be possible that experimental design allowed subjects to compensate for and correct the illusion they did experience. For example, the short distance from the subject to the viewing board allowed him to use accommodation and convergence, which do not occur when an individual ordinarily views the horizon. Had the subject been 20 feet from the viewing board, it might have affected his ability to compensate. In addition, a more satisfactory method might be created for allowing a subject to pick the stimulus circle, limiting him to look at one circle which changes size. This might reduce his ability somewhat to develop a strategy.

The results of Part 2 indicate that the alley had no effect on a subject's ability to judge the size of the circles. In fact, none of the table top objects had much of an effect. However, the foregoing criticism of the experimental design is relevant here too. A distance of eight feet may be too small to adequately test the effect of three-dimensional space in this kind of setting. The results, unfortunately, must be said to be inconclusive.

EXPERIMENT TWO

Ss viewed slides of nighttime skyline scenes and attempted to choose disks of light that were the same size as a standard disk of light projected on the screen before displaying a scene. Experiment 2a involved projected stereo slides and Experiment 2b used standard non-stereo slides.

METHOD

The procedures for both experiments were identical except for projection equipment. Each subject (S) was brought into a room and seated in a chair placed twenty feet from a screen. One slide projector was placed to his right on a table. The experimenter (E) stood or sat on the other side of the table, with the other slide projector to his left. The S was given instructions and an eye test. The lights were then turned out. One test trial was given so that Ss thoroughly understood the task. Seventeen trials were then administered. After the judgements were obtained Ss were then asked to make judgements of the distances involved in each of the skyline scenes.

Equipment. For the stereo projection, a Compco Triad Projector was used. Each slide of a skyline scene was mounted in the projector just before each trial began. The projector lamps remained off until it was time for the S to view the scene. As soon as the scene was illuminated it was focused if necessary. As soon as S made his decision and E had recorded it the projector lamps were turned off. A Minolta carousel projector was used to project the non-stereo slides. These slides were randomly mounted in the carousel before the experiment began. Again, the projector lamp remained off until S was ready to view the skyline scene. The slide was advanced into position after the standard was shown and then the lamp was switched on to illuminate the scene. Again, the projector lamp was turned off as soon as E recorded S's response.

The projector for the standard and experimental circles was a Kodak Carousel Projector with an f/3.5 4-6 inch zoom lens. The standard stimulus was separated from the experimental circles in the carousel.

The carousel was manually operated to place the standard stimulus in the projector, as was the first slide in the series of experimental stimuli. Once the series was begun the remote switching device on the projector was used to rotate the slides.

The screen used for the stereo presentation was a 48-inch square piece of Masonite covered with many layers of aluminum spray paint. The projected skyline scenes filled the entire screen. The screen used for the nonstereo presentation was a standard white lenticular ceiling-mounted screen approximately 7 feet wide and 6 feet high. The projected scene covered most of the screen, approximately 6 feet wide and 4 feet high.

Test Materials. Slides of skyline scenes: Various skyline scenes were photographed at night throughout Los Angeles using both a Stereo Realist 35-mm rangefinder camera and a Miranda Sensorex 35-mm camera. The film from the Miranda was commercially processed and mounted in standard 2 x 2 cardboard mounts. The stereo film was commercially processed and handmounted (in most cases) in metal stereo mounts, 1-5/8 inches by 4 inches. The seventeen slides used in the experiment were selected from approximately fifty exposures. Nine scenes appeared in both experiments.

Scenes varied in subject matter, from huge buildings photographed at close range to groups of buildings photographed at a distance of 1/2 to 1 mile, to horizon scenes, taken from the top of a building, stretching for miles. The order of presentation of slides was randomized for each S.

Slides of circles or disks of light: Holes were drilled in a strip of opaque exposed film with a series of small-diameter drills. The film was cut and mounted on eight 2 x 2 plastic slide mounts. (To increase the range of variance of the projected circular images during the experiment the zoom lens on the projector could be turned so that each image could be varied in size.) The resulting series of projected images thus varied from 1 to 1-1/2 inches for each slide, and the total range of variance, from largest to smallest possible image, was 7/8 inch to 6.5 inches. The projected size of the standard circle shown before each scene was 3.13 inches, approximately 3/4 of 1 degree--about the

apparent size of the actual moon. The standard circle was never shown in the series of circles projected over the skyline scene. However, the size was represented in two of the series slides. The sizes of the eight slides used in the series overlapped when each slide's total variance in size was considered. Each series was begun with a different size circle at one end of the continuum, so that "slide 3" for example, would not always be "slide 3" in every series; it could also be "slide 2" or "slide 4."

Subjects. Twenty-one of the thirty Ss were employees of The Rand Corporation, and nine were students enrolled in the introductory psychology course at Santa Monica College. None were told of the nature of the experiment except that they would be viewing nighttime skyline scenes and making perceptual judgements. About six Rand Ss were vaguely aware of the nature of the experiment through their acquaintance with E. The first half of the Ss were run in the stereo experiment and the second half in the nonstereo experiment.

Procedure. After S was seated the following instructions were spoken (not read) to him:

> You will be viewing a series of slides of nighttime skyline scenes. But before I show you each slide I'll project a circle of light on the screen. You can look at it for about five seconds, and then I'll turn it off. Then I'll project a skyline scene. Then I'll superimpose on that scene a series of circles of light, ranging from either very large to very small, or very small to very large. Your task will be to find a circle that is the same size as the circle that you saw by itself prior to the skyline scene. Are there any questions? There will be one test trial before the experiment begins so that everything will be clear.

A simple eye test was then administered in which each S was asked to read the line from the traditional Graham-Field Eye Chart which indicates 20/20 vision at 20 feet. If the S could not read that line or made a mistake, he was asked to read the next higher line (20/25 vision), then the next higher (20/30), until he read a line correctly. Using this measurement, twenty Ss had 20/20 vision, six had 20/25, one had 20/30 and two had 20/40 vision.

At this point if the S was to view the stereo slides he was asked to wear cardboard-framed stereo (polarized) glasses.

The lights were then turned out and the test trial was begun. The standard was presented with the words, "Now look at this for a few seconds." After five seconds it was turned off, and a skyline scene was projected. Then, as the series of circles of light was projected on top of the scene, E said, "Now tell me when you see the same size circle you saw before." After S made his selection, E explained how the size of each circle of light could be varied if S was dissatisfied with a particular choice of circle. After answering any further questions S might have had, E continued with the experiment, keeping conversation to a minimum.

After judgements were obtained for all seventeen scenes each S was asked to judge the distance, in terms of either feet or miles, from where the camera took the picture to a certain object or far point on the horizon, whichever was appropriate in each scene. Only one of the thirty subjects refused to complete this part of the task, claiming it was too difficult.

RESULTS

All scores were converted into ratio scores--the diameter of the circle chosen in relation to the diameter of the standard. In order to compensate for the illusion effect (if any) the subject would have to choose a circle smaller than the standard. Thus, the ratio was calculated as $\frac{\text{standard}}{\text{exp. circle}}$. This resulted in a ratio number greater than one when the experimental circle chosen was smaller than the standard. The mean size-ratios for all of the slides and for the duplicate scenes* only, for both experiments, are as follows:

	Stereo	Nonstereo
All Scenes	1.008	1.01
Duplicate Scenes	1.04	1.005

*Duplicate slides were those where the same scene was represented by both a stereo and nonstereo slide. There were nine duplicate slides in each group, and seventeen in each group for all data.

Individual subjects' mean size-ratios varied from 1.22 to .89 for stereo slides and from 1.22 to .91 for nonstereo slides. The analysis of variance (two-way, random effects) for the same data yielded:

	For all Data	For Duplicate Data
Between groups	0	2.5
Between subjects	7.57**	4.84**
Interaction	4.85**	2.25**

** $p<.01$

The slides were divided into three groups that reflected distances from the position of the camera to the farthest point on the horizon or the main object in the picture. The group with short distances contained pictures where buildings were within a few hundred yards to one-half mile away. The group with large distances consisted of pictures where the horizon was obviously two miles or farther away--usually five to ten miles. The remainder of the slides were in a middle group where distances were from one-half to two miles. There were six slides each in the far-distance and near-distance stereo and nonstereo groups. There were three slides in each of the middle-distance groups.

An analysis of variance was performed, using the ratio scores for the short-distance slides and the long-distance slides. The results are as follows:

	F Stereo	F Nonstereo
Short distance	1.54	2.13*
Far distance	3.12**	1.69

* $p<.05$
** $p<.01$

In addition, a two-way analysis of variance for interaction was performed, giving:

	F Stereo	F Nonstereo	Degrees of Freedom
Short distance versus far distance	7.31**	.313	1 164
Between Ss	4.04**	3.5**	14 164
Interaction	.36	.457	--

** p<.01

These results indicate little or no interaction. However, the significant F scores indicate that there was great variability in responses among the subjects as indicated in the first analysis. The responses to the stereo far-distance slides tended to be more varied (in the direction desired) than were they to the short-distance slides. This is further illustrated in Table 1.

Table 1

Range of Ratio Scores Indicating Presence of Illusion

	Range of Ratio Scores			
	1.22-1.29	1.30-1.39	1.40-1.92	Total
Stereo				
Far-distance slides	14	6	2	22
Short-distance slides	6	5	2	13
Nonstereo				
Far-distance slides	1	5	2	8
Short-distance slides	4	3	2	9

It is clear from this table that the far-distance slides in the stereo experiment yielded far more ratio scores indicating an illusion effect than did any of the other groups. However, this must be considered to only be a trend, since the means of the ratios for this group were no greater than 1.05 (See Figure 1).

Subjects' judgements of distances in the slides were plotted on a horizontal bar graph (Figure 2) according to the three groupings: far distance, near distance and middle distance. In general, subjects' judgements stayed within the boundaries of a normal distribution of the groupings in which the slides were placed according to physical distances. Short-distance judgements ranged from two feet to 1-1/2 miles, middle distance judgements varied from 100 feet to five miles and far distance judgements ranged from 1/2 mile to forty miles. On the whole, it would be safe to say short distances were judged more accurately than middle and far distances.

In addition, medians were calculated of the subjects' judgements of the far distances, and were plotted in relation to the actual distance in the scene.* As indicated in Figure 3 in the stereo slides, subjects judged distance to be closer as real distance increased. However, the same relationship was not present in the nonstereo slides. It should be noted that the slides in these two groups were of the same scenes except in the one case indicated.

DISCUSSION

The overall results indicate that only a minute illusion was obtained. The analysis of variance for all data indicates much intersubject variability, and the significant F for interaction indicates that the variables had an effect on the observers' judgements. Further analysis indicates that the variability is due to the high percentage of ratio scores, indicating an illusion effect for the far-distance slides in the stereo group. In addition, there is a very striking trend for subjects' judgements of far distance in the stereo slides. These results will be discussed in more depth in the general discussion following.

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*Physical distance in each scene was estimated by distance on a map.

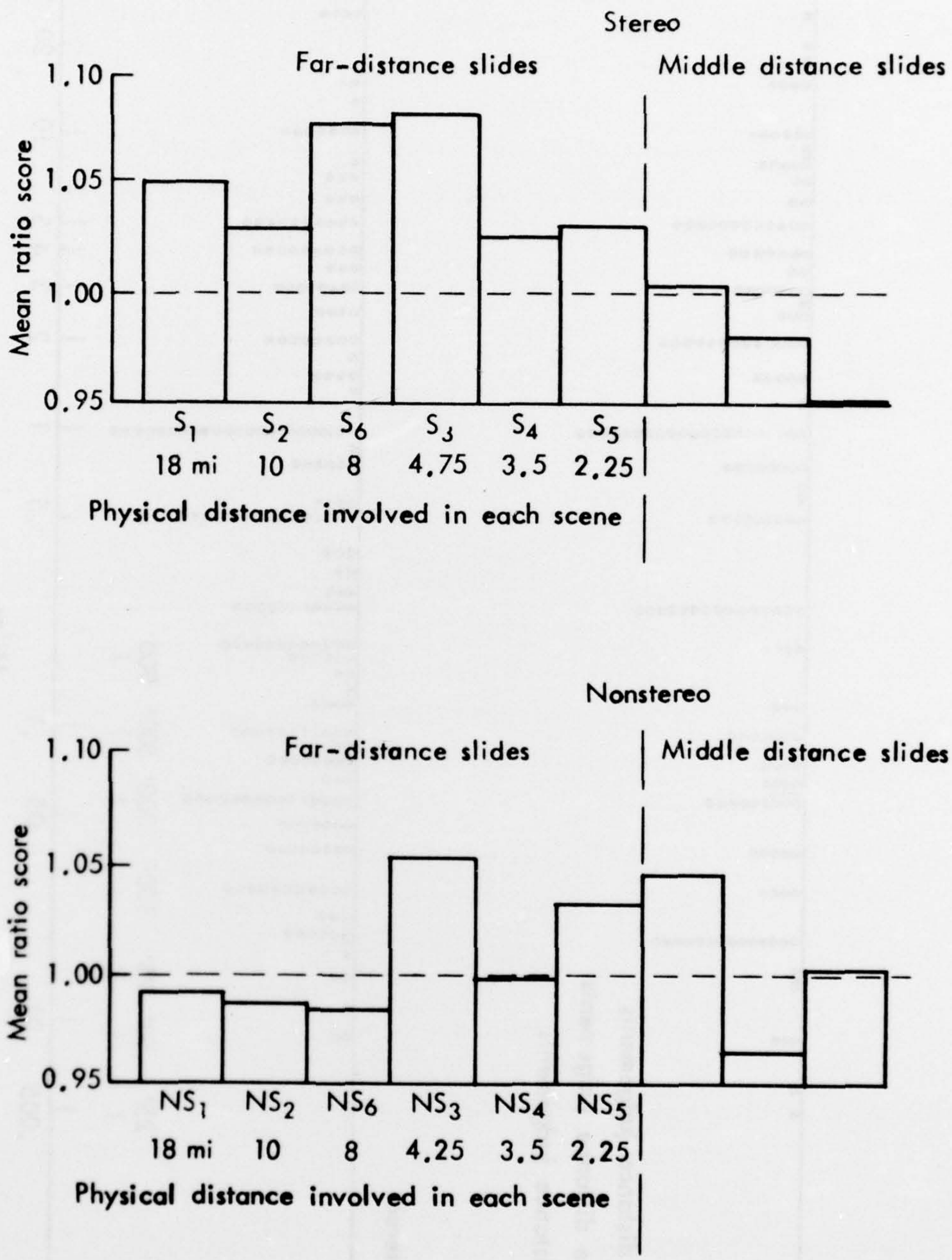


Figure 1. Mean Ratio Scores Obtained by Subjects Viewing Stereo and Nonstereo Far-Distance and Middle-Distance Slides

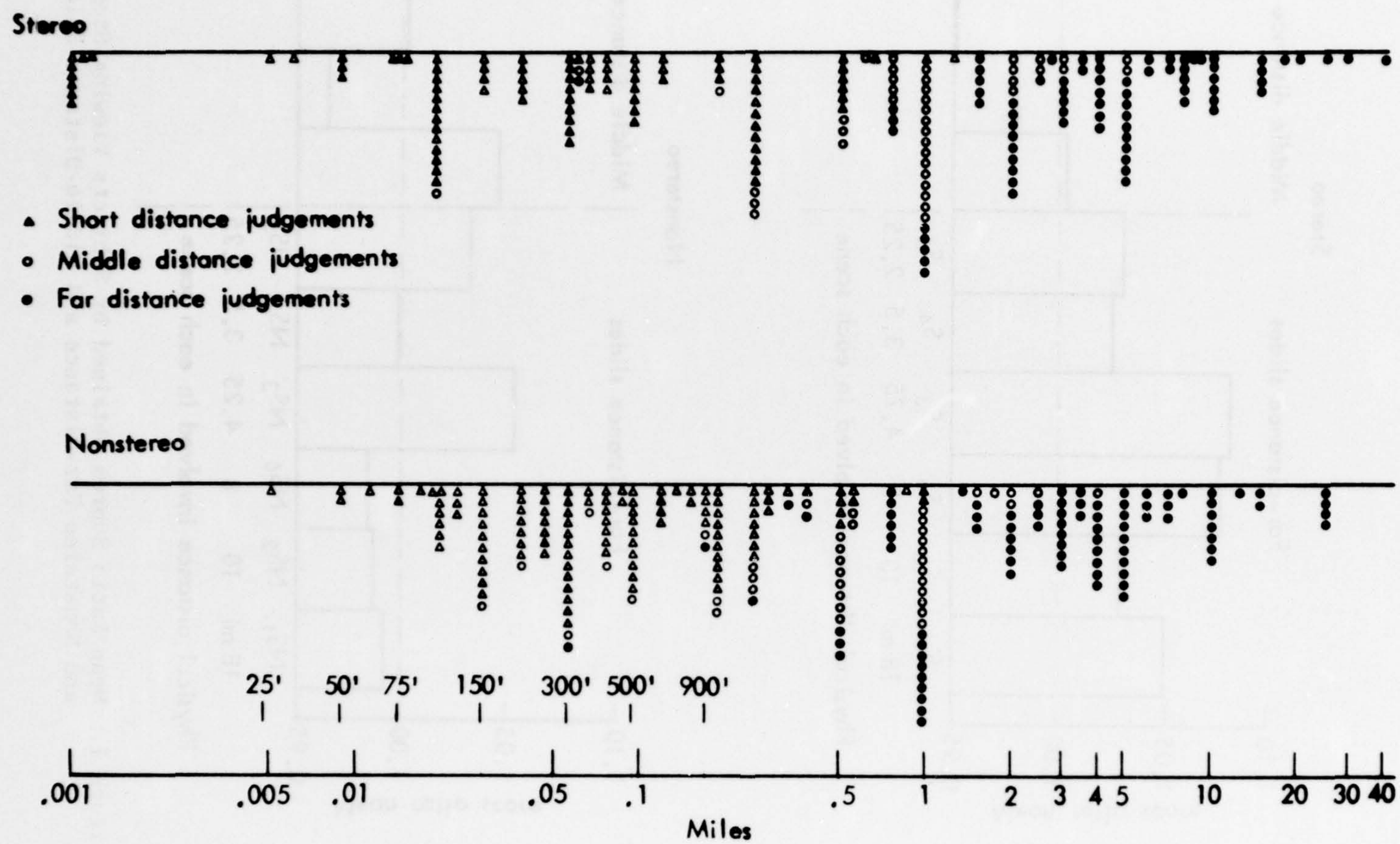
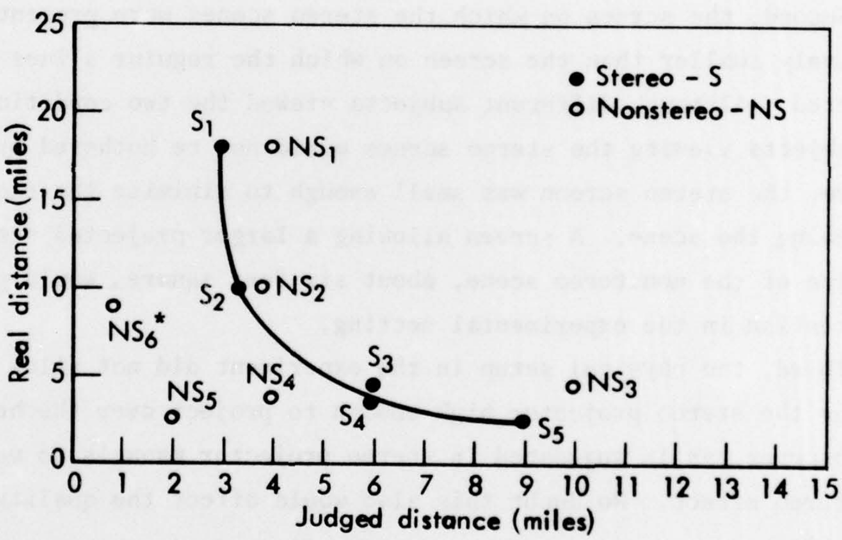


Figure 2. Distribution of Subjects' Distance Judgements



***The judgement data for the comparable stereo slide were not used because judgement were made for an intermediate distance in the slide and not the far distance.**

Figure 3. Medians of Subjects' Judgements of Far-Distances Plotted as a Function of Physical Distance

The results obtained in Experiment 2a are encouraging enough, in spite of the low *mean* ratio scores, to suggest that the use of stereoscopic presentation of slides is an effective way of studying the moon illusion. However, there appear to be certain methodological problems to be overcome before more definitive results can be obtained.

First, the method of presenting the experimental circles could be improved. The use of individual slides of circles presented in orderly sequence allows the subject to be more accurate or discerning in his judgement, using a process of elimination. However, an iris diaphragm placed in a projector used as a light source, for example, would allow a continuous increase or decrease in size of the comparison circle and give the subject less assistance in making his decision.

Second, the screen on which the stereo scenes were presented was relatively smaller than the screen on which the regular slides were projected. Although different subjects viewed the two conditions and the subjects viewing the stereo scenes would not be bothered by this feature, the stereo screen was small enough to minimize the experience of viewing the scene. A screen allowing a larger projected scene about the size of the nonstereo scene, about six feet square, would provide more realism in the experimental setting.

Third, the physical setup in the experiment did not allow for placing the stereo projector high enough to project over the head of the observer, as is suggested in stereo projector manuals to maximize the stereo effect. No doubt this also would affect the quality of stereo projection.

Another criticism of the experimental setting might be that the extraneous light coming through the windows in the exit doors of the room allowed cues in the room itself to be used in making judgements. This might have affected the results more seriously than the other problems just mentioned. Again, being able to view cues in the room could help to minimize the stereo effect.

GENERAL DISCUSSION

The results of the two experiments support Kaufman and Rock's conclusion that slides or stimuli simulating two dimensions will not recreate the moon illusion and that depth is a very important ingredient in creating it. However, they feel that configurational properties such as interposition and perspective, as they are related to depth, are the important stimulus correlates. The results of Experiment 2a in a sense challenge that opinion.

The slides that yielded a statistically significant effect were *not* of scenes with an abundance of configurational properties. Instead these scenes projected great depth or sense of distance which was enhanced by stereo projection, with a minimum number of objects in the scene giving cues to distances. The combination of great depth and few cues thus produced scenes which were perceptually ambiguous.

A major difference between the present experiment (number 2) and Kaufman and Rock's experiments was that most of the latters' subjects viewed scenes during the day, while all of my scenes were of the night-time sky. Daytime scenes normally contain a considerably greater number of cues than do nighttime scenes. Consequently, a daytime sky could affect one's thinking about a hypothesis differently from a nighttime sky. A scene most often recalled when the moon illusion is discussed is one in which a seemingly huge moon is observed over the ocean at night. The moon is seen through space of an indeterminate distance without the benefit (or at least minimal benefit) of "relationships within the stimulus pattern," to quote Kaufman and Rock (1962:1028).

The scenes in the present experiment that contained the greatest number of configurational properties or relationships within the stimulus pattern were the short- and middle-distance slides. Although the data are not included in Table 1, the middle-distance slides provided about the same number of ratio scores above 1.2, proportionately, as the short-distance slides. If a high density of configurational properties were necessary for a sense of depth, then the scenes that involved distance up to two miles (middle-distance slides) should have yielded as many high ratios as the far-distance scenes.

CONFIGURATIONAL PROPERTIES AND DEPTH

The next step is to look at the kinds of stimulus patterns present in the far-distance slides. Three of the six slides were photographed from the top of a five-story building, and offered a panoramic view of the Santa Monica area. Lights from many buildings and cars diminished in the distance to the horizon, where they abruptly ended. Some buildings appeared in the foreground (within two or three blocks of the building where the picture was taken). Another slide was taken from the middle of a freeway overpass, using a timed exposure so that red taillights on the right side of the picture and white headlights on the left side of the picture converged on the horizon. Two slides were of scenes overlooking the nighttime ocean, photographed from the top of a bluff. Both were of coastal lights running along the edge of Santa Monica Bay, one of the northern coastal line where no lights from buildings in the foreground or of cars on the highway could be seen. Only distant lights from 10 to 18 miles were visible. The other slide was taken looking south, and contained lights from the highway and buildings in the near and middle distances. The major quality of these six scenes was that distances in the far-distance slides were difficult to judge. Both the experimenter's and the photographer's judgements as to distances in the actual scene were incorrect, when compared to physical distances as plotted on a map. The configurational properties of the far-distance slides can thus be characterized as very uniform and as presenting ambiguous stimulus cues.

If the configurational properties alone were responsible for the illusion effect obtained, then stereo and nonstereo slides should have produced the same result. However, the fact that they did not suggests that the additional sense of depth created by the stereoscopic presentation was the crucial variable here. Since configurational properties are not essential to the real moon illusion (e.g., the moon over the ocean), it appears that visual sensation of depth is the critical variable in the moon illusion. Not just depth per se, that is, but depth with cues that are perhaps misleading or that leave distance indeterminate (not regulated by specifiable cues as Epstein, Park and Casey [1961] define it).

It will be recalled that Kaufman and Rock were unable to obtain significant results in a planetarium, and that they could not explain why in the light of others' positive results, such as Schur's already cited. Gruber, King, and Link (1963) obtained significant results (mean ratio score of 1.61) when subjects judged illuminated ping-pong balls against a "luminous ceiling" in an otherwise totally dark room. They also obtained significant results when the ceiling was briefly illuminated and then darkened, leaving only the horizon line illuminated. When they had subjects make judgements about the balls without a ceiling, no illusion effect was obtained. Although subjects were only six feet from the stimuli, it would seem appropriate to say that they were in a situation which duplicates the nighttime sky without any other stimulus patterns, where distance is indeterminate, or not regulated by specific cues.

Although configurational properties may play a major role in creating the feeling of depth necessary to create the moon illusion, they seem inadequate to explain the work done in dark rooms or the results of Experiment 2 in this paper.

PERCEIVED DISTANCE VERSUS PHYSICAL DISTANCE

The most interesting part of the result, which on first glance is surprising, is that subjects' judgements of distance for the stereo far-distance slides varied inversely with the slides' real distance. This finding bears a similarity to findings where objects in space are reported to be nearer when they are actually farther away. Epstein, Park, and Casey report work done by Heinemann, Tulving, and Nachmias in 1959, where subjects were asked to judge which of two successively presented disks was farther away. The comparison was held constant at 1°. The explanation given was that the matches were consistently "in the direction of size constancy": the farther away an object was, the larger it was judged. Dees, 1966, performed three experiments in which subjects were trained to make distance estimations in space as a function of stereopsis (stereoscopic vision) alone, stereopsis plus motion parallax, and motion parallax alone using a motion-picture stereoscope. The result of interest here is that during training for Experiment 1,

many subjects had a very difficult time accepting the experimenter's corrections when they reversed the order of judged distances. The explanation Dees presented was similar to Kaufman and Rock's, discussed in the Introduction, concerning the inconsistency of the moon's looking larger and closer when it should appear larger and farther away. Dee's subjects reasoned thus: if the target is a constant size and appears to change size as a function of distance, it must be closer. However, what subjects should be telling themselves, according to Dees, is that if the angular size of the target remains constant and if the target appears to change in size as a function of distance, then where the target appears larger the stereopsis cues must be yielding the automatic interpretation that the target is farther away.

It seems that the size-distance invariance hypothesis is unsatisfactory as an explanation of this phenomenon, especially when Kaufman and Rock go so far as to assert that distance cues are registering without the awareness of the subjects, who then make a conscious judgement of distance based on size. If distance judgements had been obtained at the same time as ratio judgements, an argument could be made that apparent distance of the circle of light affected the apparent distance of the scene. However, that was not the case. In this situation the cues for distance were reversed for the stereo far-distance slides, or at least subjects made decisions in reverse as a result of the ambiguity of the scene, completely independent of seeing any moon illusion. A scene that gave very ambiguous cues as to its true distance was overestimated when it depicted a short distance such as two miles and underestimated if it involved a long distance such as 20 miles. This suggests that explanations of the moon illusion based on subjects making assumptions about distance are spurious. That the moon looks larger and closer when it should look farther away is an artifact of what is really going on.

To summarize, Kaufman and Rock state that studying configurational effects will lead to a better understanding of the moon illusion. However, my results indicate they are important only insofar as they contribute to the observer's subjective experience of depth.

Thus, the crucial variable to be studied next is visually experienced depth.

ANISOTROPY OF VISUAL SPACE

How would an explanation based on the hypothesis of the anisotropy of visual space, as suggested in the Introduction, handle the data in the second experiment presented? Recalling Tschermak-Seysenegg's conclusions, discussed in the Introduction, that "equal objective visual angles or arcs of the sky are overestimated at low elevations and underestimated at high elevations" (1952:215), it follows that if an object in the sky, such as the moon, subtends an equal objective angular distance both at the horizon and in the zenith, and if that arc of space is seen as larger lower in the sky than it is in the dome of the sky, then the object filling the sky must appear subjectively larger.

In the case of the judged-distance/real-distance result obtained here, the implication of this hypothesis is that the subject may have incorrectly estimated the arc of the sky in the slides where he was judging distance. For example, in the slides where great distance was represented, the cues were ambiguous enough to cause the subject to overestimate the arc of the sky, making the configurational properties seem larger and closer. He would then make his decision of distance on the basis of that reaction.

This is, of course, only speculation based on Tschermak-Seysenegg's data; however, it is an hypothesis that is experimentally testable. Luneberg's mathematical model of visual space would then provide an analytical framework for describing the metrical relationships involved.

Experimentally, what could be done using stereo slides would be the following: in addition to obtaining subjects' judgements about the size of horizon moons in comparison to zenith moons, judgements as to distance, elevation, and angular size would be obtained. It would require that corresponding physical data also be obtained. Then, using Luneberg's proposed metric, the visual data could be mapped according to the physical data. And the presence or absence of the moon illusion could thus be related to the resulting directional properties of visual space. The present data suggest that this would be a potent direction for further research.

CONCLUSION

The current hypothesis attempting to explain the moon illusion have been reviewed. Two experiments were conducted which tested the contextual-effects hypothesis and a variation of the size-distance invariance hypothesis. No illusion was obtained in Experiment One. A modest illusion was obtained in the second experiment where stereo slides depicted great distance and offered few contextual cues thus producing a visual scene of ambiguous depth. Neither hypothesis adequately explained this result. In addition another hypothesis was presented, which might handle many inconsistencies that have cropped up in past experimentation and in the second experiment. This has to do with the possible anisotropy of visual space and how it could be handled using Luneberg's mathematical theory of binocular vision.

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